Doing the Best Acoustic Test with Articles that are Large Relative to the Size of the Chamber

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Spacecraft Mechanical Section/Dynamic Environments & Aerospace Nuclear Safety Engineering

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Overview

- Background
- Development test objectives and approach
- Significant test cases
- Test configuration and results with short (bottom) simulator configuration
- Test configuration and results with tall (full) simulator configuration
- Mars 2020 test configuration and results
- Important findings and future work

Background

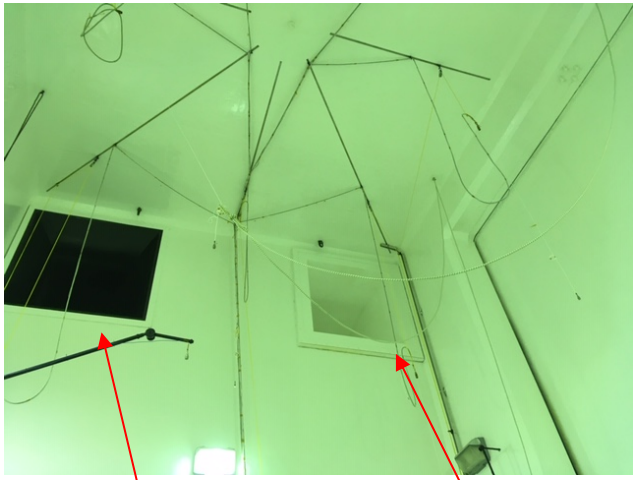
- Some JPL missions have test articles whose dimensions challenge the conventional capabilities of the JPL acoustic chamber
  - Upcoming: Mars 2020, Europa Clipper
  - Volumes at or exceed 10% of chamber volume and/or dimensions create significant spatial blockage (e.g. Mars 2020 girth ~40% of chamber lateral area, ~2 ft. from walls)

- Difficulties experienced in previous test with large test articles
  - MSL (acoustic test in Dec 2008) dimensionally identical to Mars 2020
    - Response (non-control) mics around test article measured on average ~3 dB below control mics which were all located above test article
    - Some measurements theorized to have been influenced by proximity to test article (surface absorption and reflection)

- Development testing undertaken in 2018-2019 with objective to optimize control strategy to get best sound field for large test articles

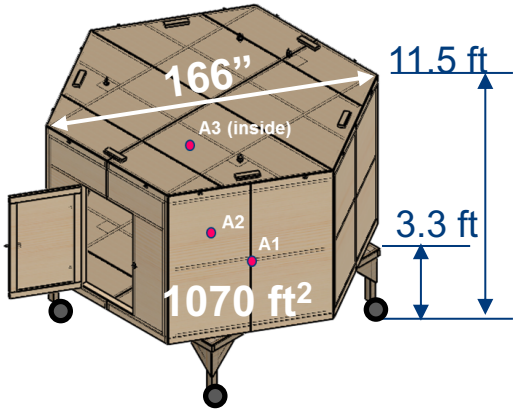
JPL Acoustic Chamber

- Dimensions
  - L = 22 ft (264 in); W = 19.5 ft (234 in); H = 26 ft (312 in)
  - Volume: ~11,000 ft^3
- Sources
  - WAS-3000 modulator (~650 Hz upper frequency) / 35 Hz horn
    - Horn located at upper SW corner of chamber
    - Control band up to 1 kHz
  - 1100 W (continuous) 3-way loudspeakers
    - Control band 1 kHz – 10 kHz
    - Only 1 available during development testing (lower SW corner)
    - 4 operational during Mars 2020 test (lower SE and SW corners)

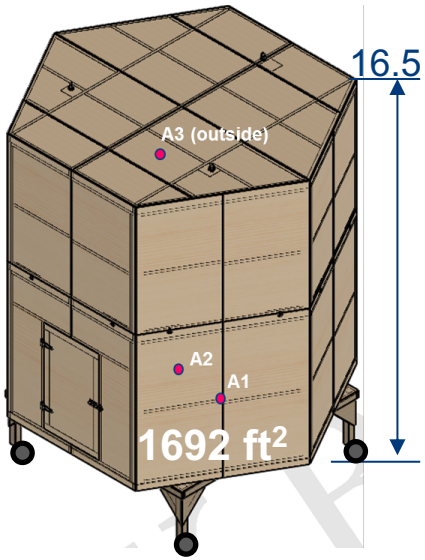


Test Approach Using Volumetric Simulator

Plywood frame construction



Bottom configuration
9.7% of chamber volume



Full configuration
15.3% of chamber volume

Bottom configuration in chamber

Full configuration in airlock

- Use volumetric simulator to emulate insertion of large test articles into chamber
  - Bottom configuration to simulate Mars 2020 volume and dimensions
  - Full configuration to simulate large and tall test articles such as Europa Clipper
- Start with conditions for MSL test and vary control parameters to find best control strategy for large test articles in the chamber
- Apply control strategy with Full configuration simulator

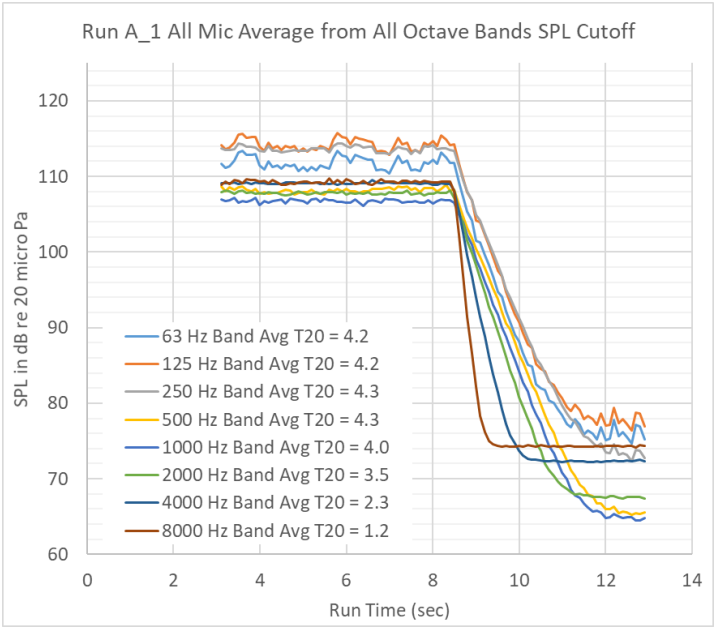
Simulator Comparisons with MSL

- Simulator Bottom configuration parameters vs. MSL/Mars 2020

Parameter	MSL/Mars 2020	Simulator (Bottom)
Max lateral dimension	178” diameter	166” corner-to-corner
Volume (approximate)	1120 ft^3 (10.2% chamber)	1070 ft^3 (9.7% chamber)
Acoustic absorption	See T60 table below	See T60 table below

Test Article T60 (sec)

Band	MSL Ctrl	MSL Resp	Bottom Sim	Bottom Sim w Foam	Full Sim no Foam	Mars 2020
63	2.6	3.5	4.2	3.6	3.7	3.7
125	2.6	3.5	4.2	3.5	3.7	3.7
250	2.8	3.7	4.3	3.2	3.7	3.8
500	3.2	4.0	4.3	2.0	3.7	4.1
1000	3.0	3.8	4.0	2.0	3.6	3.9
2000	2.9	3.8	3.5	1.8	3.0	3.1
4000	--	--	2.3	1.4	2.1	3.1



T60 values are measure of room reverberance – inversely proportional to acoustic absorption

- Lower value → higher absorption → more acoustic power needed to achieve level

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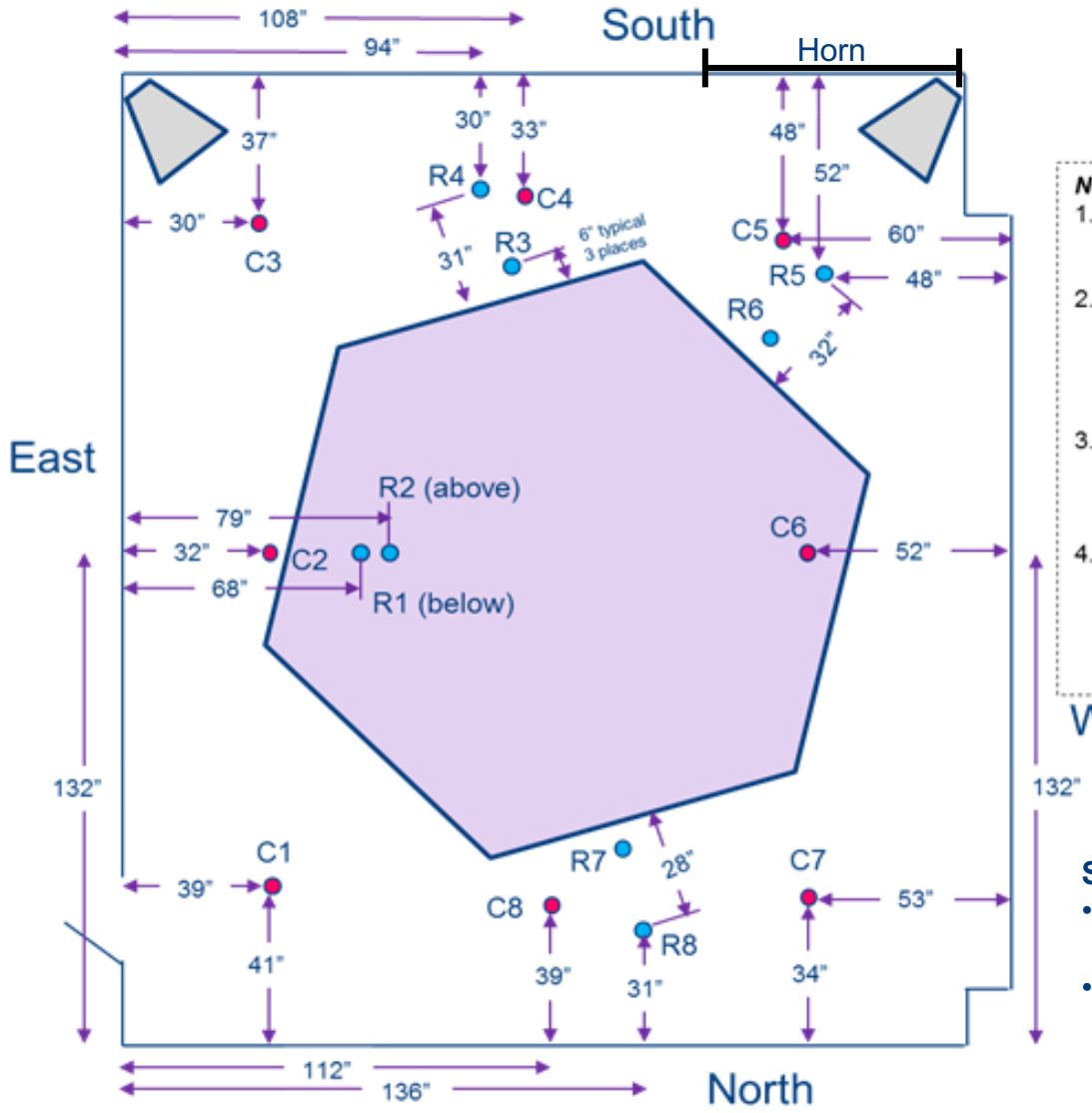
Significant Test Cases

Description	Configuration	Objectives
Bottom Simulator with Microphones Placed Above Test Article	• Bottom Simulator • WAS-3000 • One Loudspeaker	Establish performance of chamber with “MSL” version of simulator and microphones placed similarly to MSL acoustic test
Bottom Simulator with Microphones Distributed Around Test Article	• Bottom Simulator • WAS-3000 • One Loudspeaker	Determine the effect on the controller of spatially distributing microphones around test article
Bottom Simulator with Absorptive Material on Top Surface	• Bottom Simulator with Absorptive Treatment • WAS-3000 • One Loudspeaker	Investigate the effects of absorptive material on the sound field close to the test article, as well as overall in the chamber
Full Simulator with Distributed Microphones	• Full Simulator • WAS-3000 • One Loudspeaker	Examine whether the chamber could perform well with a test article over 15% of the volume of the chamber, and a relatively high input spectrum
Mars 2020 Acoustic Test	• Mars 2020 Launch Configuration • WAS-3000 • Four Loudspeakers • Microphones Distributed Around Test Article	Implement control strategy developed in simulator studies to successfully perform testing on flight hardware that is relatively large for the chamber

Control Mics Above Simulator



Legend:
- Control Mic
- Response Mic

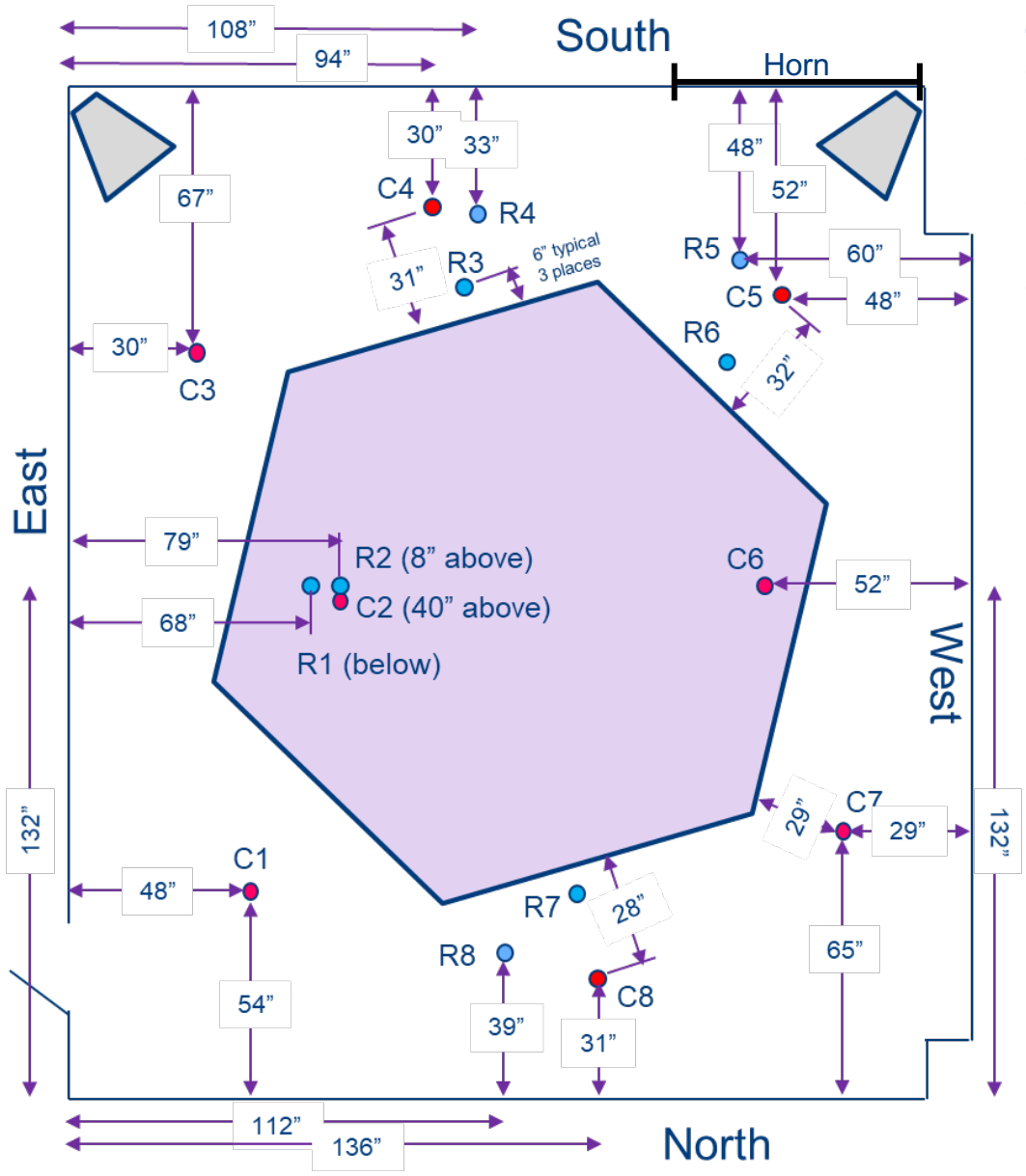
Notes:
1. Simulator not present in Empty Chamber tests
2. R1 is 11 inches below the bottom of the VS stand (28" from floor), R2 is 8 inches above the top surface
3. R4, R5 and R8 are located at the Figure 2 positions of C4, C5 and C8, respectively
4. R3, R6 and R7 are at the same height as R4, R5 and R8, respectively, and normally aligned wrt the simulator surface

Sound sources:
- Modulator/35 Hz horn upper SW corner
- 1 loudspeaker operational (lower SW corner)

Chamber Dimensions:
North-South: 22 ft (264")
East-West: 19.5 ft (234")
Height: 26 ft (312")

Mic#	Floor Height (ft.)
C1	16' 4"
C2	14
C3	15' 4"
C4	16
C5	13
C6	14
C7	17
C8	15' 4"
R1	6" below
R2	6" above
R3	8
R4	8 (Fig 2 C4)
R5	6.5 (Fig 2 C5)
R6	6.5
R7	6.5
R8	6.5 (Fig 2 C8)

With Control Mics Distributed Around Simulator



Control mic location strategy:

- Achieve good spatial average around test article while mitigating surface influence
- Use 8 control mics
- Place at random clocking and heights around test article
- Maintain at least 30” from test article or chamber surfaces

Notes:

1. Simulator not present in Empty Chamber tests
2. R1 is 11 inches below the bottom of the VS stand (28” from floor), R2 is 8 inches above the top surface
3. Control and Response locations swapped from Fig. 1: C4 with R4, C5 with R5, C8 with R8
4. R3, R6 and R7 are at the same height as C4, C5 and C8, respectively, and normally aligned wrt the simulator surface. Their positions should not have changed from Fig 1.

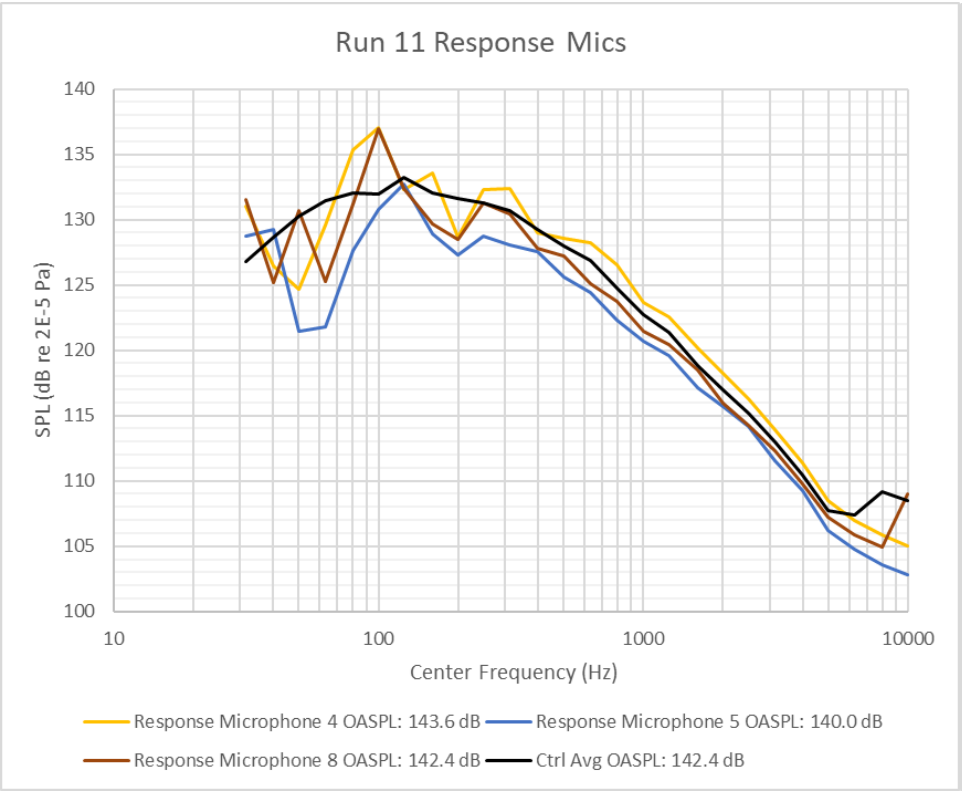
Legend:

- Control Mic
- Response Mic

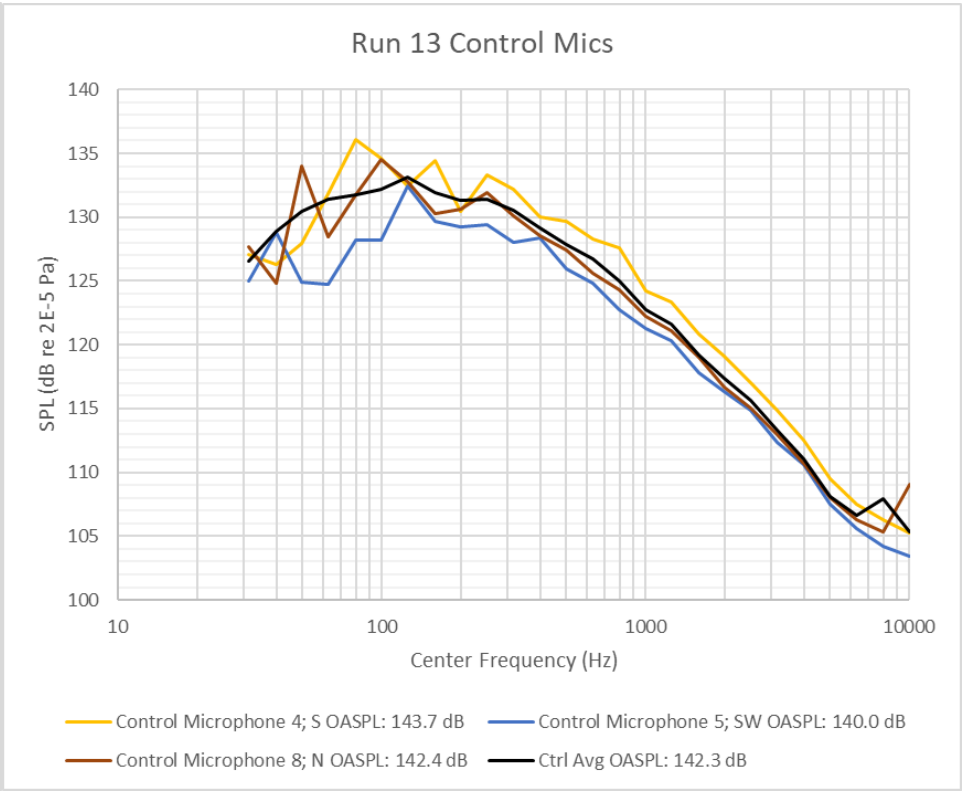
Mic#	Floor Height (ft.)
C1	4
C2	14
C3	6.5
C4	8
C5	6.5
C6	14
C7	9
C8	6.5
R1	6” below
R2	6” above
R3	8 (Fig 1 R3)
R4	16 (Fig 1 C4)
R5	13 (Fig 1 C5)
R6	6.5 (Fig 1 R6)
R7	6.5 (Fig 1 R7)
R8	15’ 4” (Fig 1 C8)

Field Around Simulator: Above vs Distributed Control

With control mics above simulator



With control mics distributed around simulator

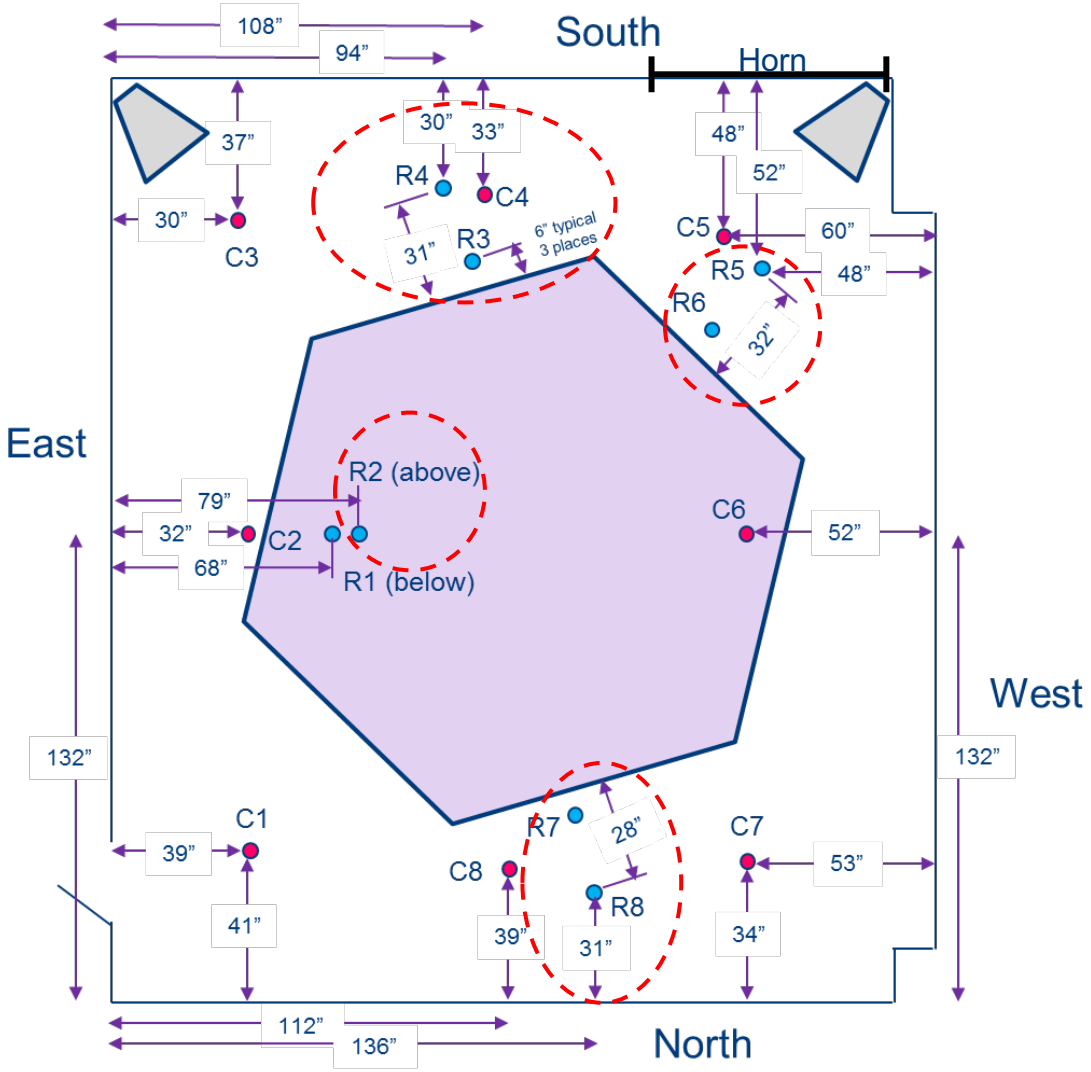


Response mics around simulator, at least 30” away

Response mics for Run 11 used as control mics for Run 13

- Distributing control mics around test article provides more consistent sound field around the test article

Surface Proximity Effect

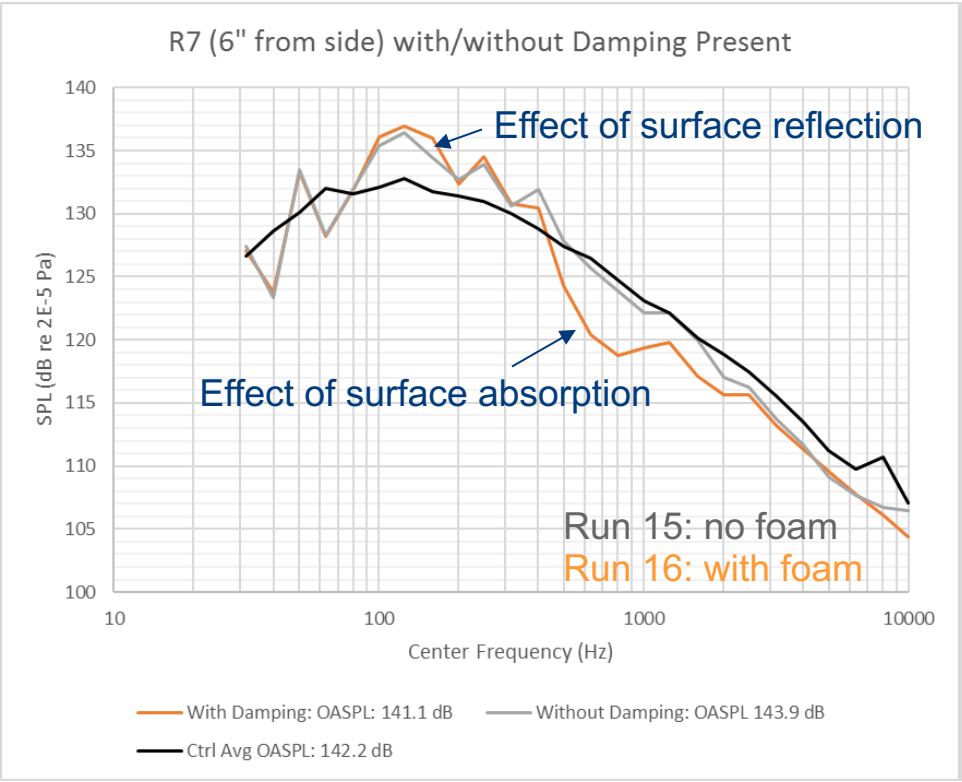


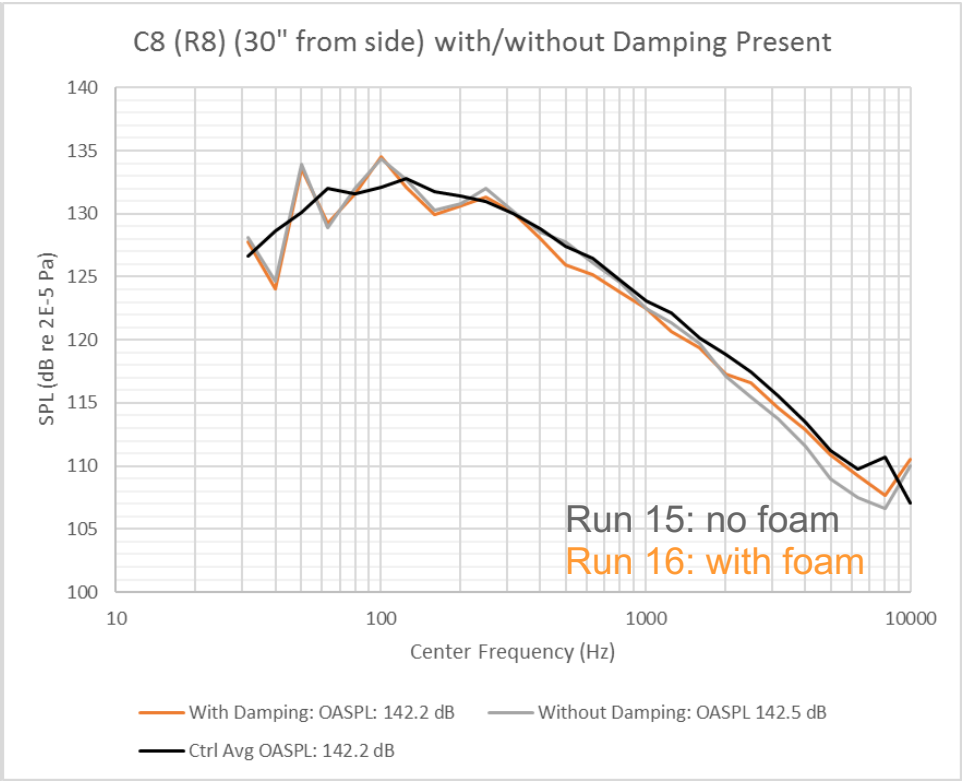
- Three paired locations 6” and ~30” from simulator side

6”	~30”	Height
R3	R4	8 ft
R6	R5	6.5 ft
R7	R8	6.5 ft
Control mics are above simulator		

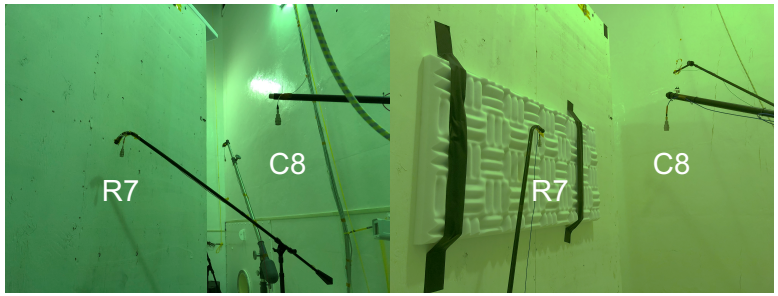
- Also, response mic R2 placed 8” above top of simulator

Proximity Effect (cont.)





- R7 is 6” from simulator side with foam directly in front. C8 is same location but 30” back from simulator side
- Effect of additional surface absorption at 6” distance is clear between 400-2000 Hz
- Effect of additional surface absorption at 30” distance appears negligible
- Effect of surface reflection between 100 – 300 Hz seen with or without added foam



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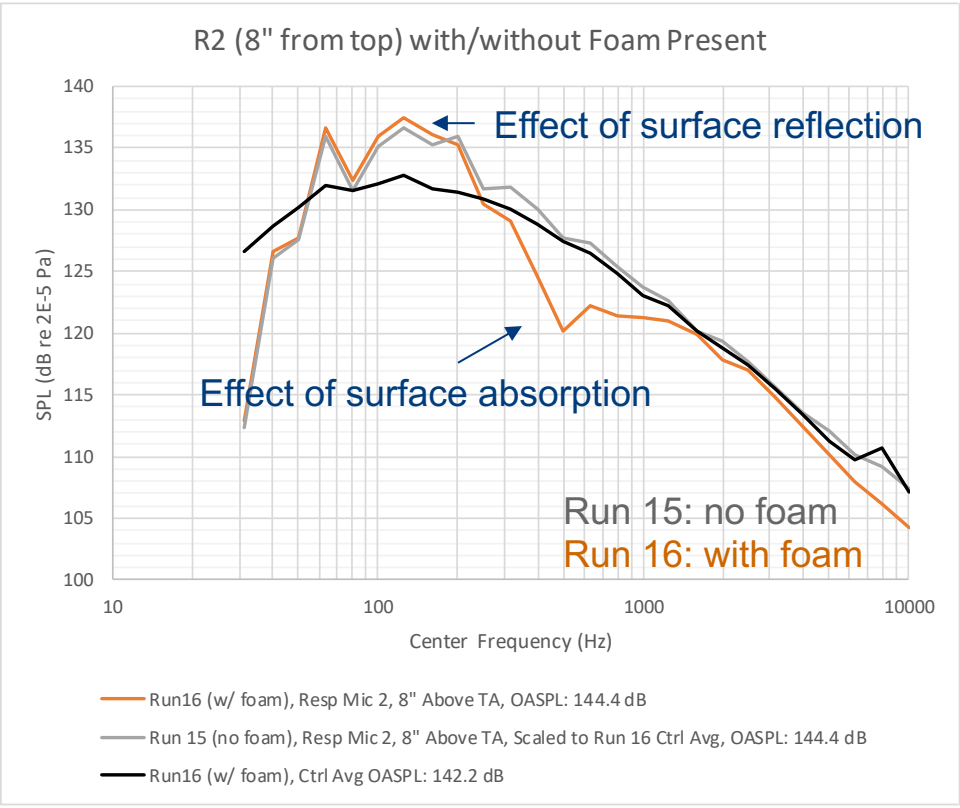
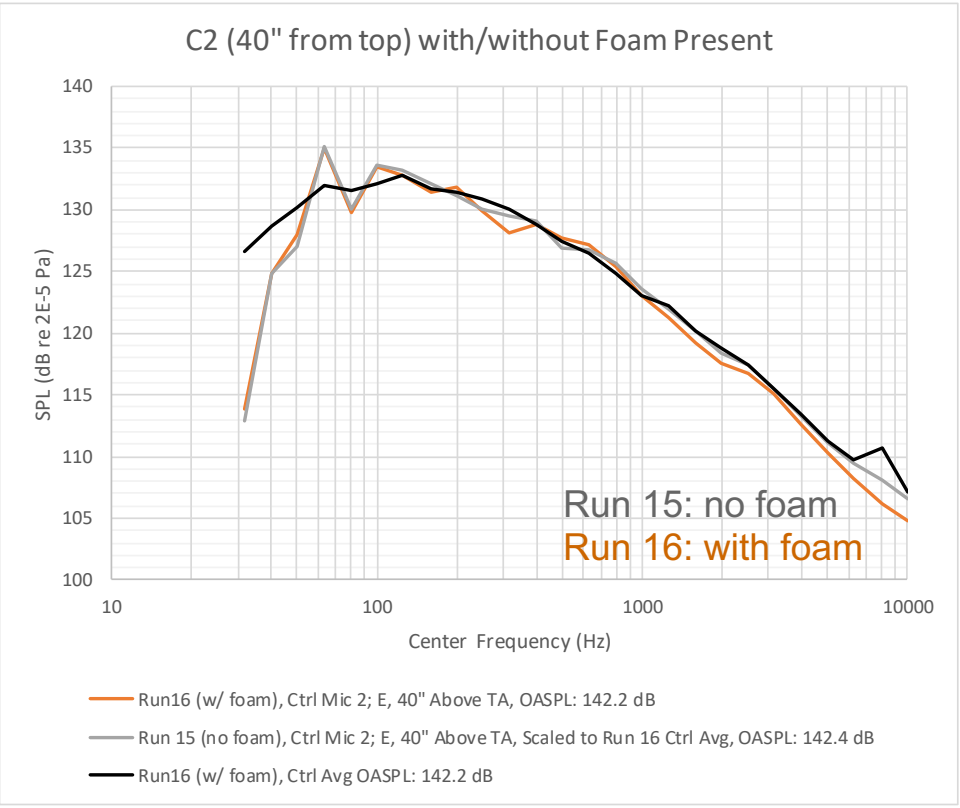
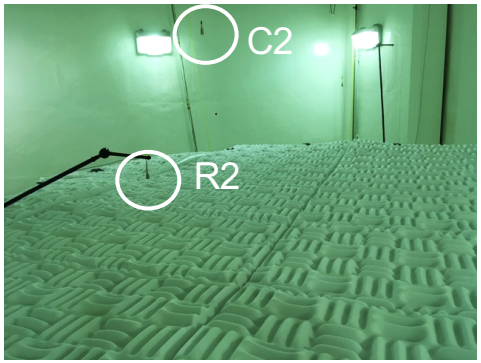
Proximity Effect (cont.)



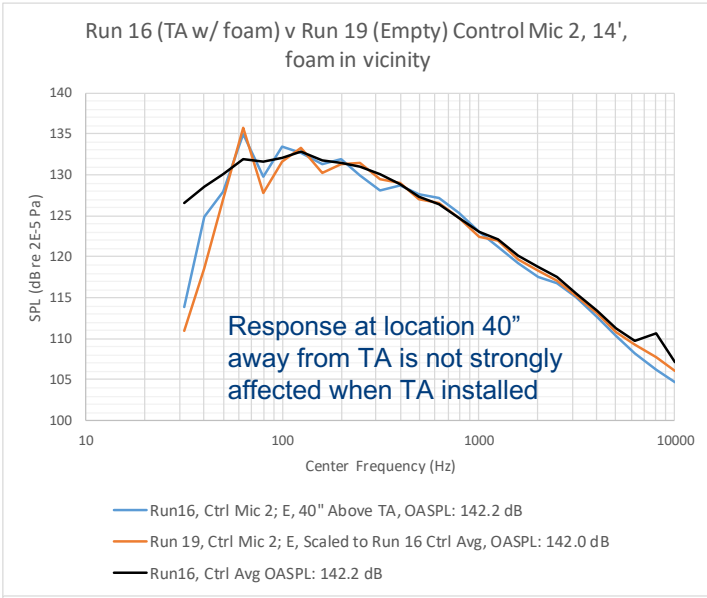


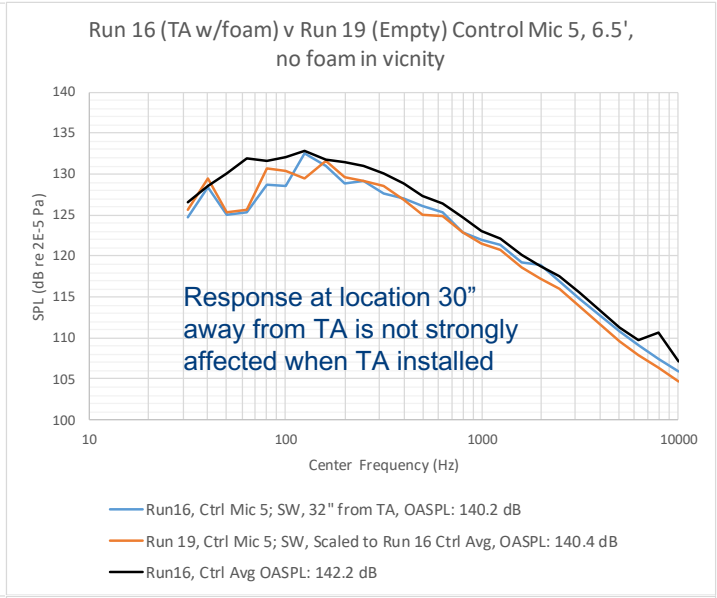
- R2 is 8” from simulator top with foam directly above. C2 is same location but 40” above simulator top
- Effect of additional surface absorption at 8” distance is clear between 300-1500 Hz
- Effect of additional surface absorption at 40” distance appears negligible
- Effect of surface reflection between 100 – 250 Hz seen with or without added foam



Proximity Effect – Compared with Test Article (TA) Removed

Locations ≥ 30” from TA



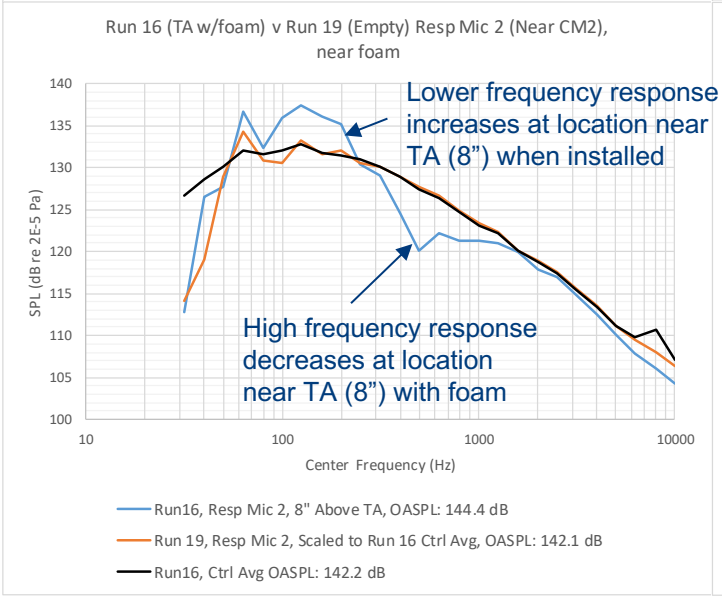


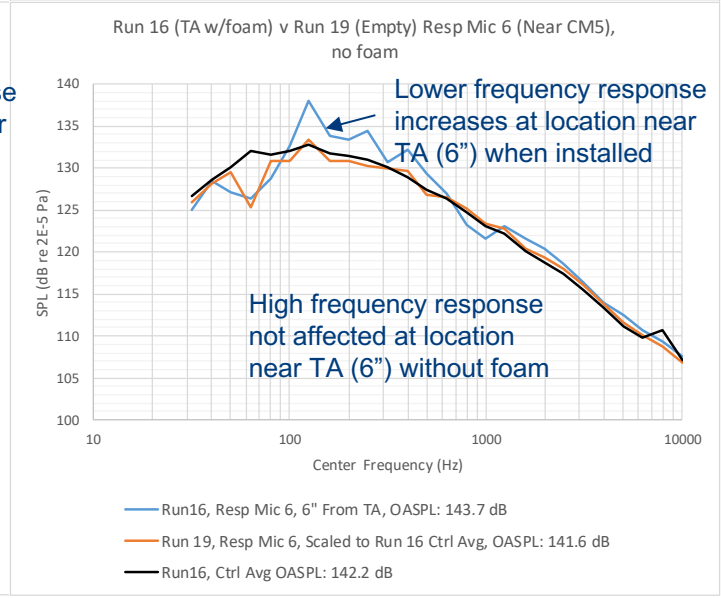
Run 16: TA with foam
Run 19: Empty Chamber

Introduction of test article (TA) box does not greatly influence mic responses that are at least 30” from TA.

TA influences lower frequencies by influencing room acoustic mode shapes.

Locations Close to TA



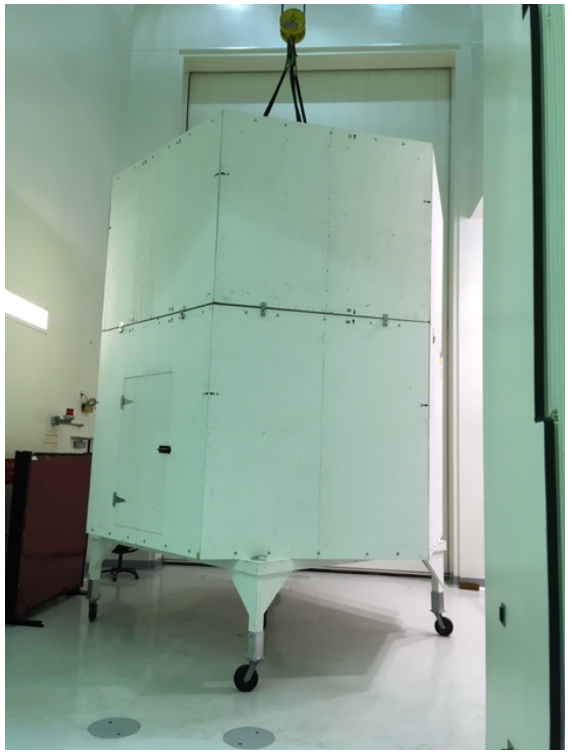


Introduction of test article (TA) box has significant effect on mics located close to box.

Responses generally higher due to reflection from TA, except at higher frequencies where local absorption reduces the response levels.

Full Simulator Configuration

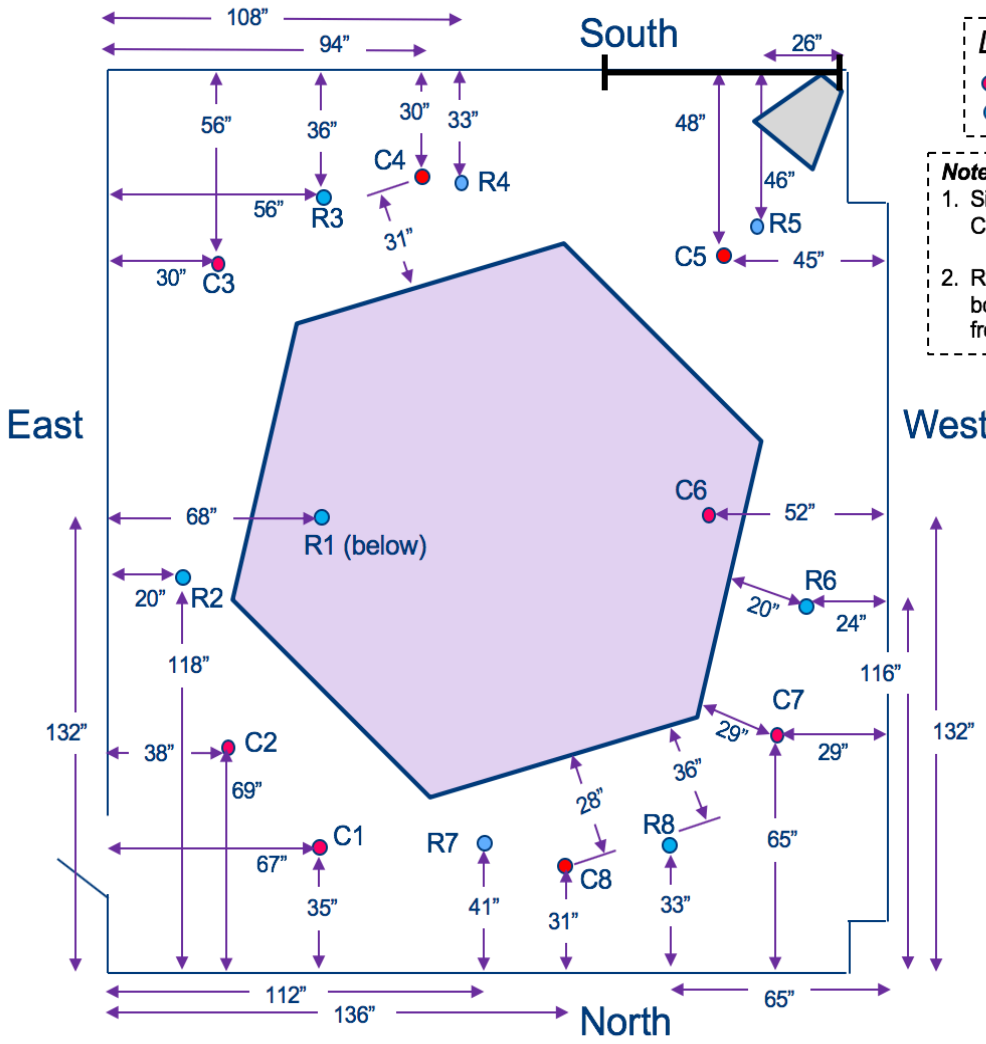
Full simulator in airlock



Full simulator in chamber

- Construction = 3/8” plywood on 2x4 frame
- Total volume = 15.3% of chamber volume
- Height from floor = 16.5 ft
- Box vertical dimension = 13 ft
- Box maximum lateral dimension = 166”

Full Simulator Test Control Mic (red) Locations



Legend:
- Control Mic
- Response Mic

Notes:
1. Simulator not present in Empty Chamber tests
2. R1 is 11 inches below the bottom of the VS stand (28” from floor)

Control mic location strategy:
- Achieve good spatial average around test article while mitigating surface influence
- Use 8 control mics
- Place at random clocking and heights around test article
- Maintain at least 30” from test article or chamber surfaces
- Test article rotated to avoid parallel surfaces

Mic#	Floor Height (ft.)
C1	4
C2	15
C3	8
C4	12
C5	8
C6	19.25
C7	13
C8	10
R1	2.4
R2	11
R3	5
R4	15
R5	6.25
R6	6.5
R7	20
R8	4.25

Chamber Dimensions:
North-South: 22 ft (264”)
East-West: 19.5 ft (234”)
Height: 26 ft (312”)

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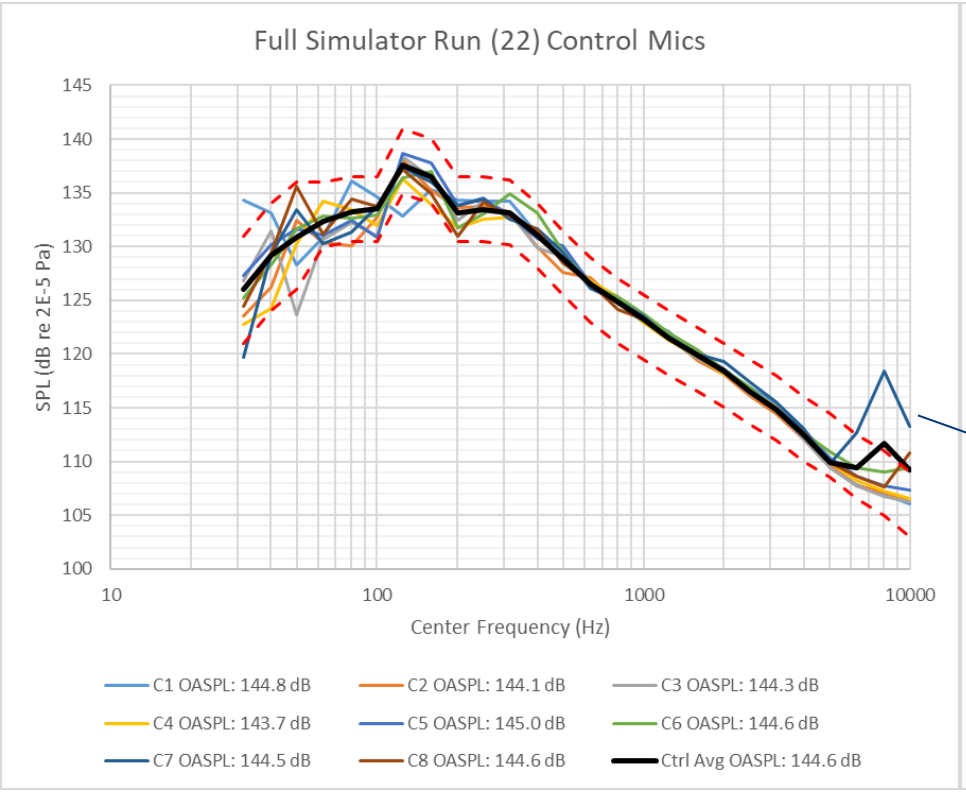
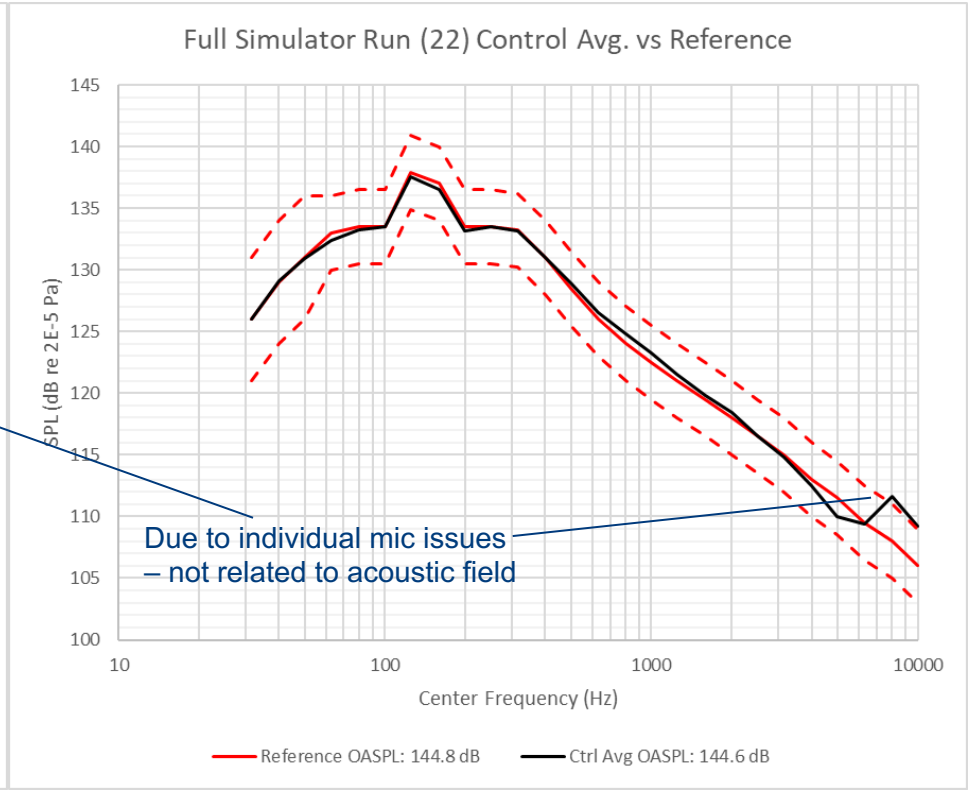
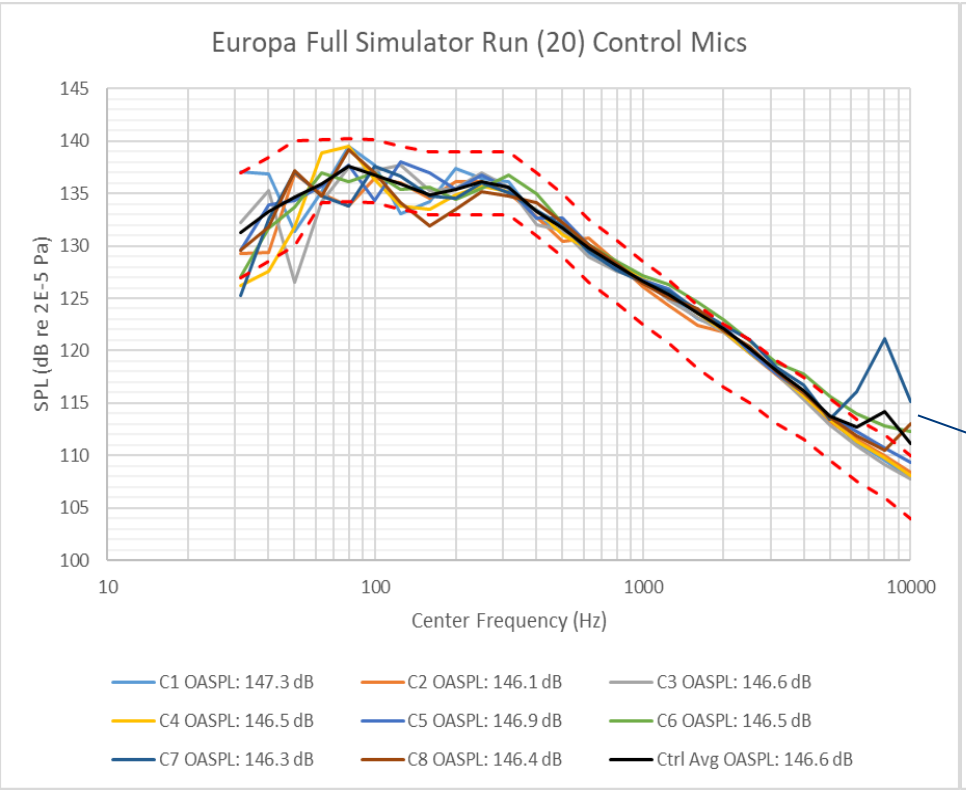
Full Simulator Acoustic Test Mic Data

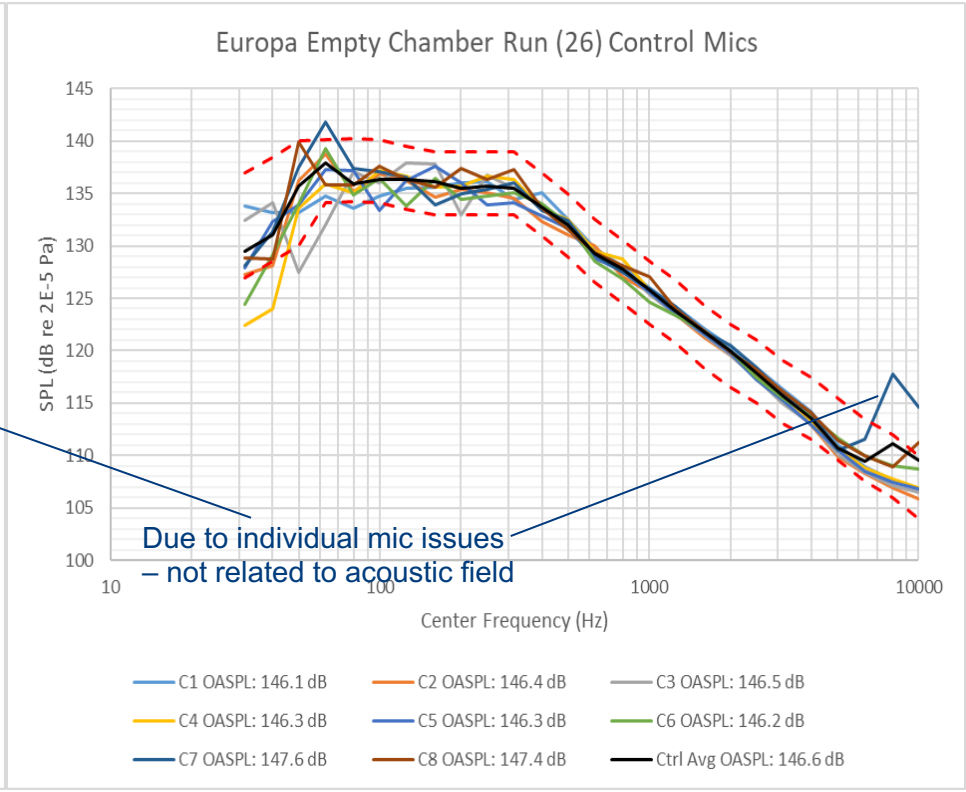




- Chamber performs well with full simulator and generic EELV envelope input
  - Control average close to nominal profile
  - Mic-to-mic variation similar to empty chamber

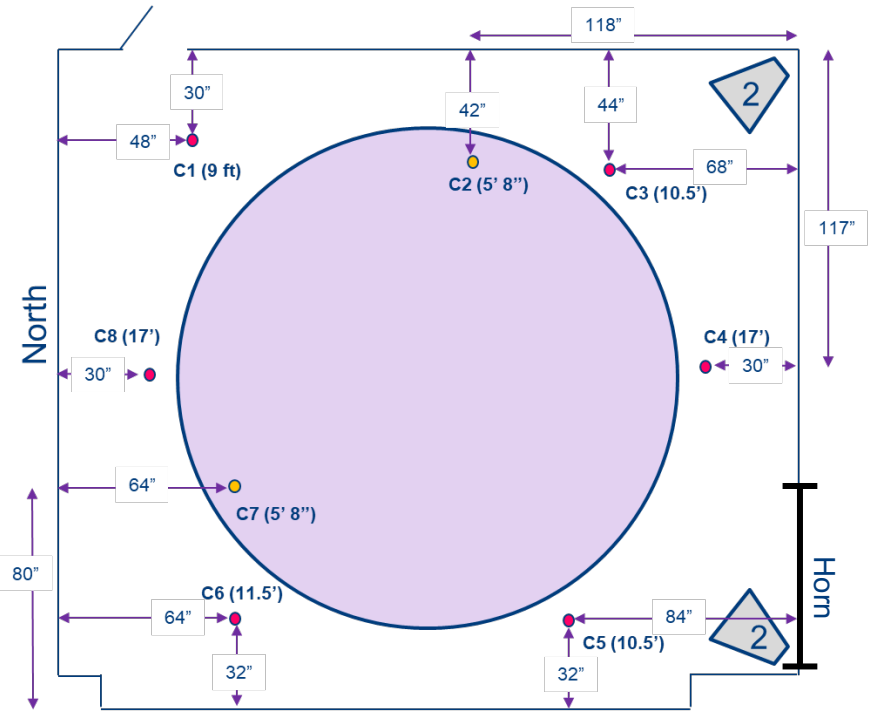
Full Simulator Acoustic Test Mic Data





- Chamber performs well with full simulator and Europa Clipper Input
  - Overall 146.6 dB vs nominal 146.9 dB
- High frequency input near upper tolerance, likely due to increased spillover from WAS-3000 (650 Hz design) due to increased power demand with test article present

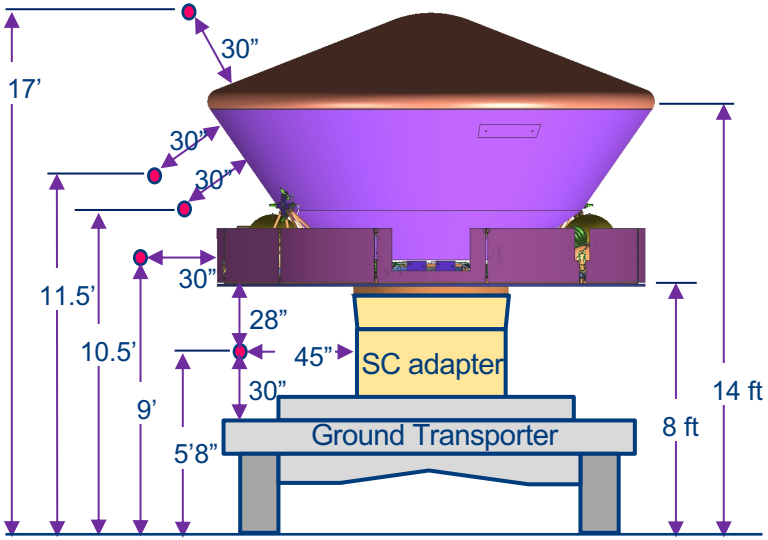
Mars 2020 Acoustic Test Control Mic Locations



Plan view

Legend:
- Control Mic
- Response Mic

Mic#	Height from Floor
C1	9 ft
C2	5 ft 8 in
C3	10.5 ft
C4	17 ft
C5	10.5 ft
C6	11.5 ft
C7	5 ft 8 in
C8	17 ft
R1	
R2	
R3	
R4	
R5	
R6	
R7	
R8	
R9	



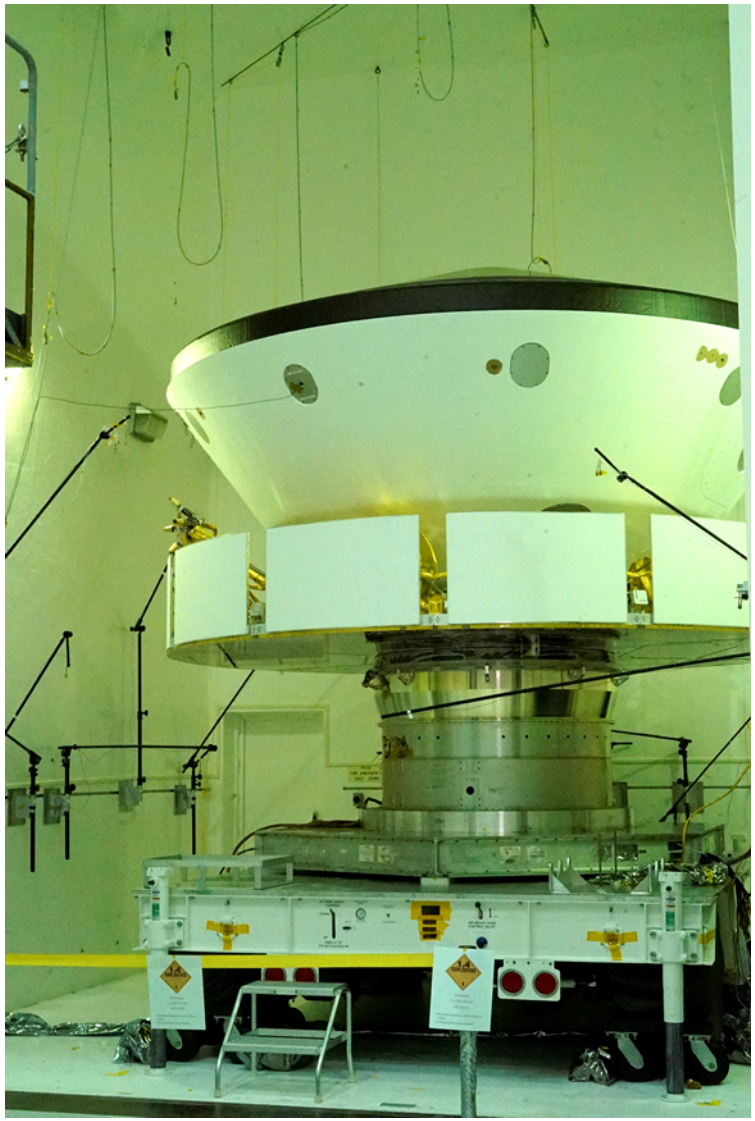
Radial and axial positions wrt test article (circumferential positions suppressed for clarity)

Sound sources:
- Modulator/35 Hz horn upper SW corner
- 4 loudspeakers (lower SE and SW corners)

Chamber dimensions:
North-South: 22 ft (264”)
East-West: 19.5 ft (234”)
Height: 26 ft (312”)

Test article dimensions:
Volume: 10.2% of chamber volume
Maximum diameter: 178”

Mars 2020 in JPL Acoustic Chamber



Mars 2020 Flight Vehicle acoustic test

April 12, 2019

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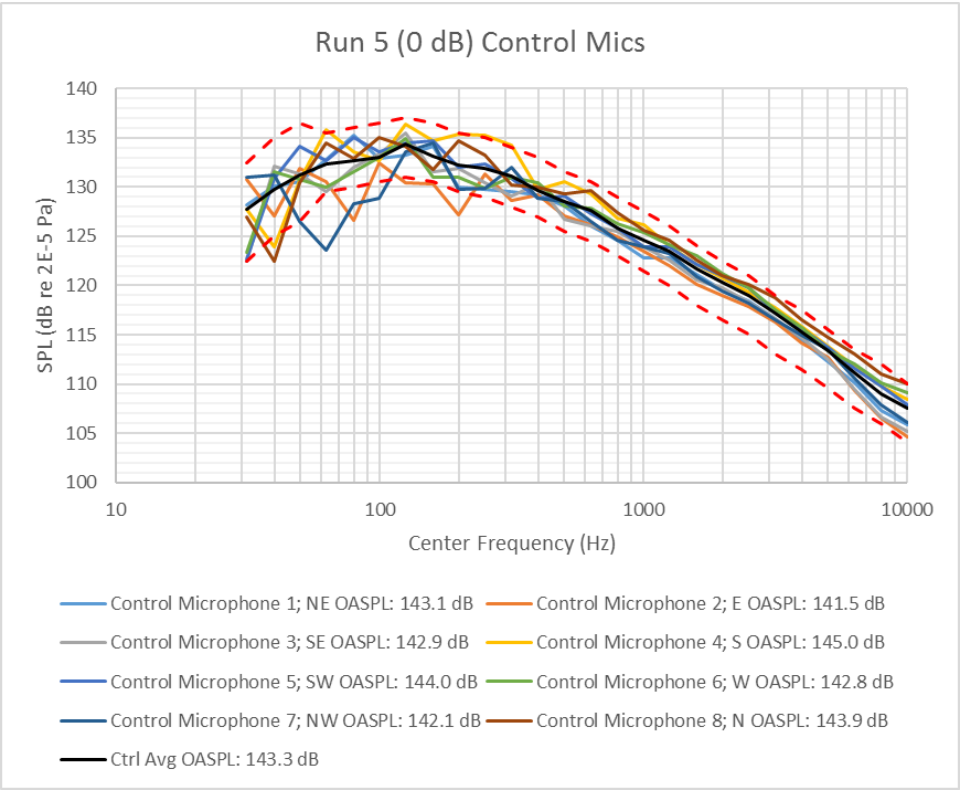
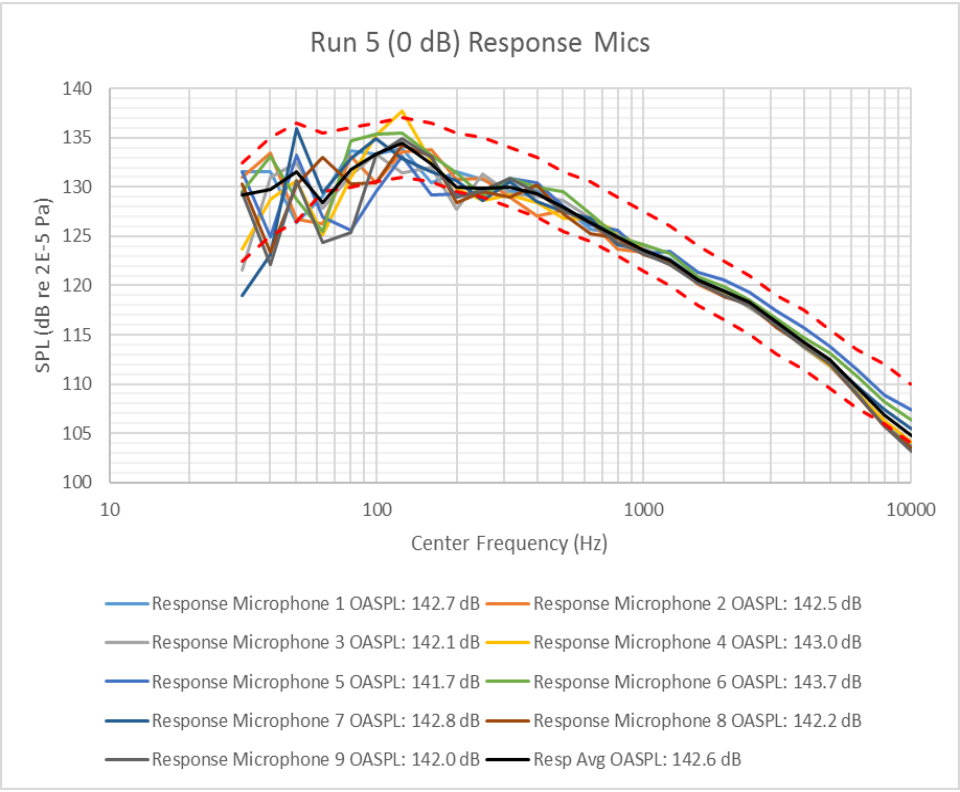
Mars 2020 Acoustic Test Mic Data

Control Microphones



Response (non-control) Microphones



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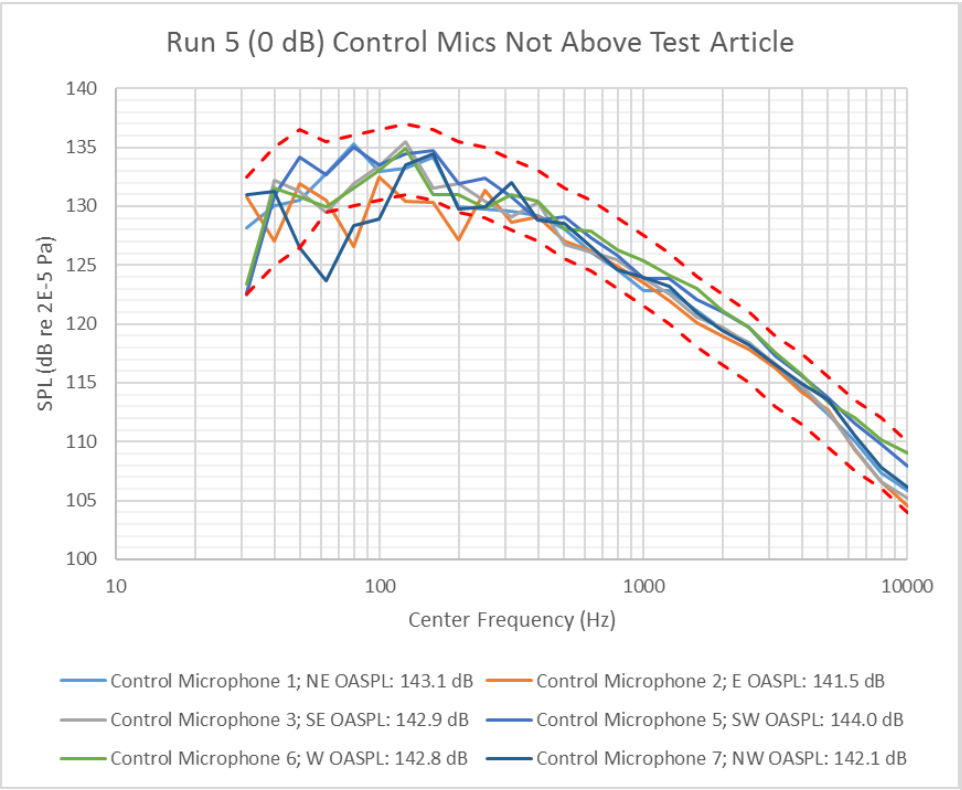
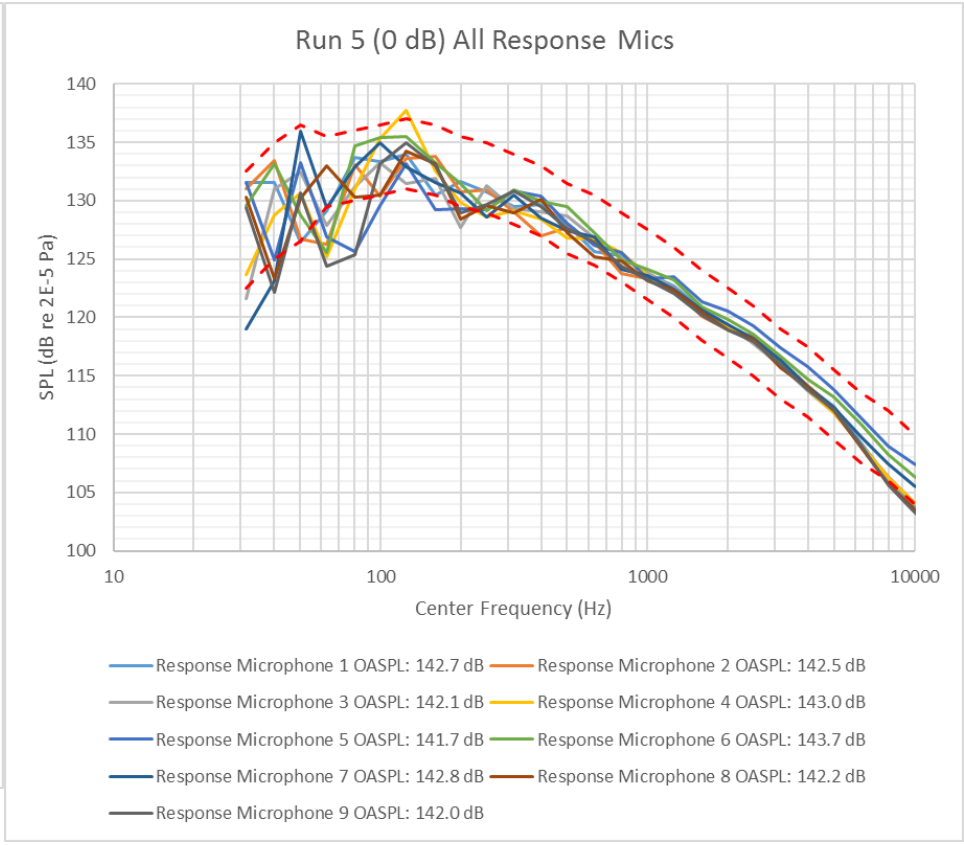
Mars 2020 Control and Response Mic Comparison

Control mics around and below test article (not above)



Response (non-control) microphones around and below



- Non-control mics in-family with control mics in same spatial region

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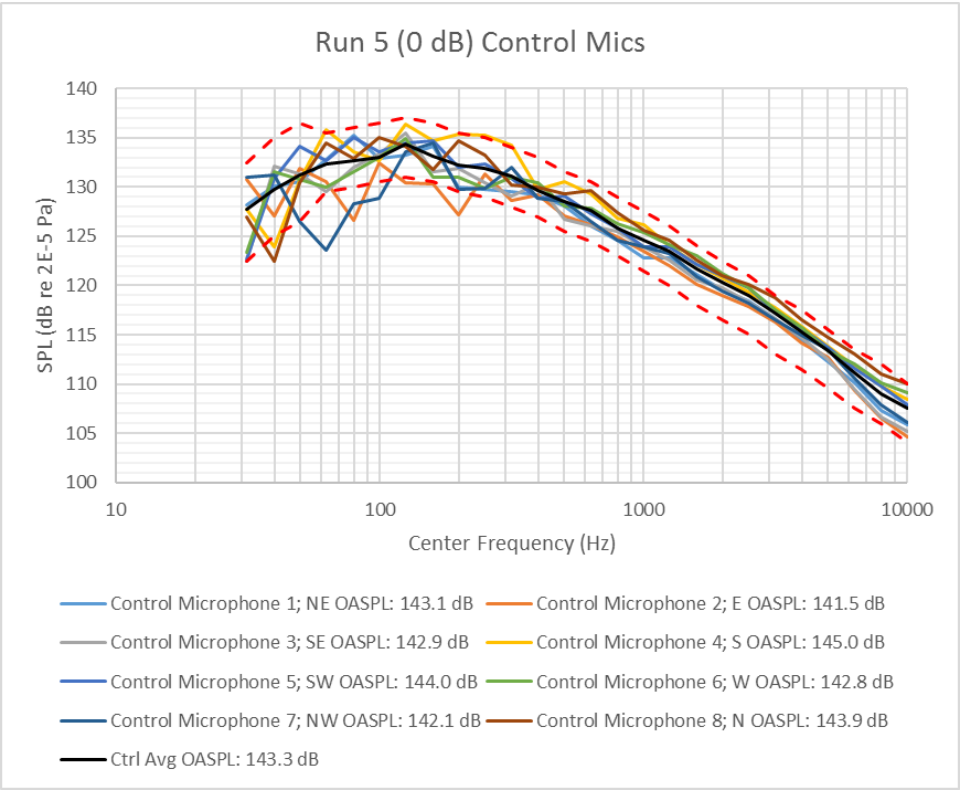
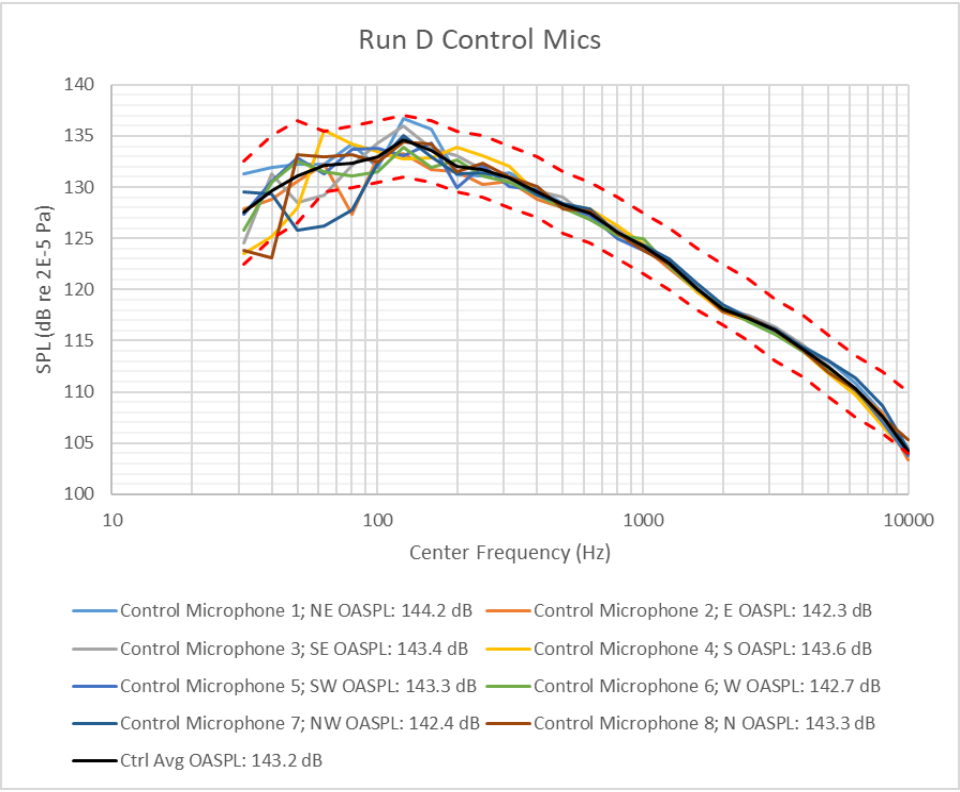
Mars 2020 Test Article vs Empty Chamber Runs

With Test Article



Empty Chamber



Major Findings

- Consistent sound field successfully achieved in tolerance with large test articles up to ~15% chamber volume with optimized control strategy

- To get an adequate sampling of the average sound field around the test article
  - Use enough control mics (JPL used 8, more may be better but with diminishing returns)
  - Control mics spaced randomly around test article (circumferentially and axially)
  - Keep control mics at least 30” away from chamber walls and large test article surfaces to avoid surface proximity effects
    - Avoid augmented levels due to surface reflection and diminished levels due to surface absorption

Future Work

- Future work
  - Develop pre-test model simulation approach as a tool to plan control mic placement customized for a given test article
    - Correlate model with test data

- Enhance loudspeaker configuration to optimize control of high frequency bands

Acknowledgements

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